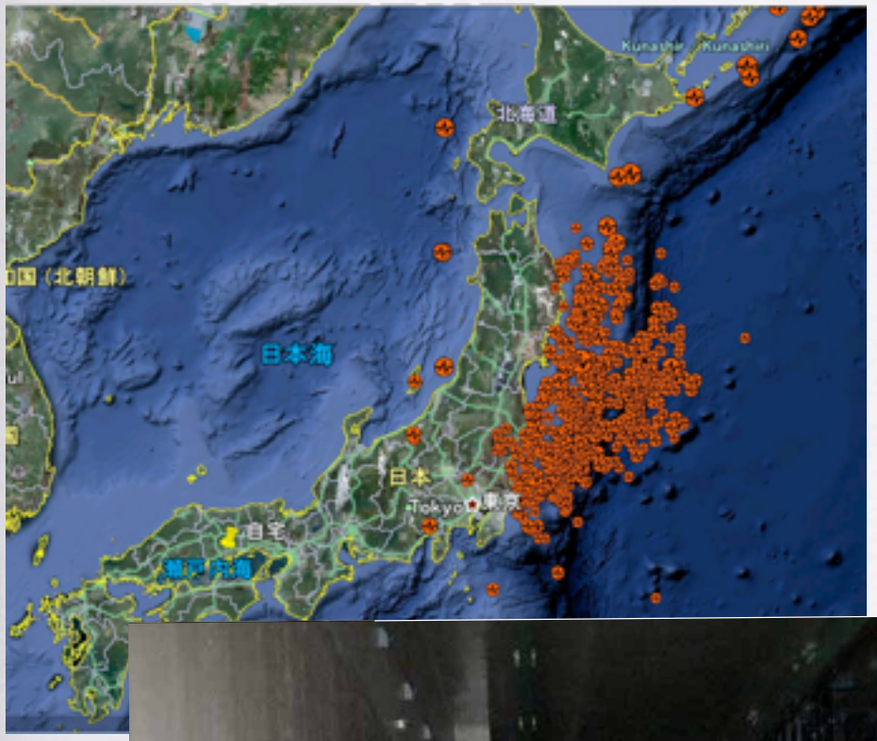
In John E's room

SUSY discovery and reconstruction

Mihoko M. Nojiri
KEK & IPMU

- come back here after all disasters

Earthquake



Tsunami

KEK linac

J-PARC at Tokai

//f.hatena.ne.jp

And Fukushima accident -- An example of public relation

General public forced to learn radiations

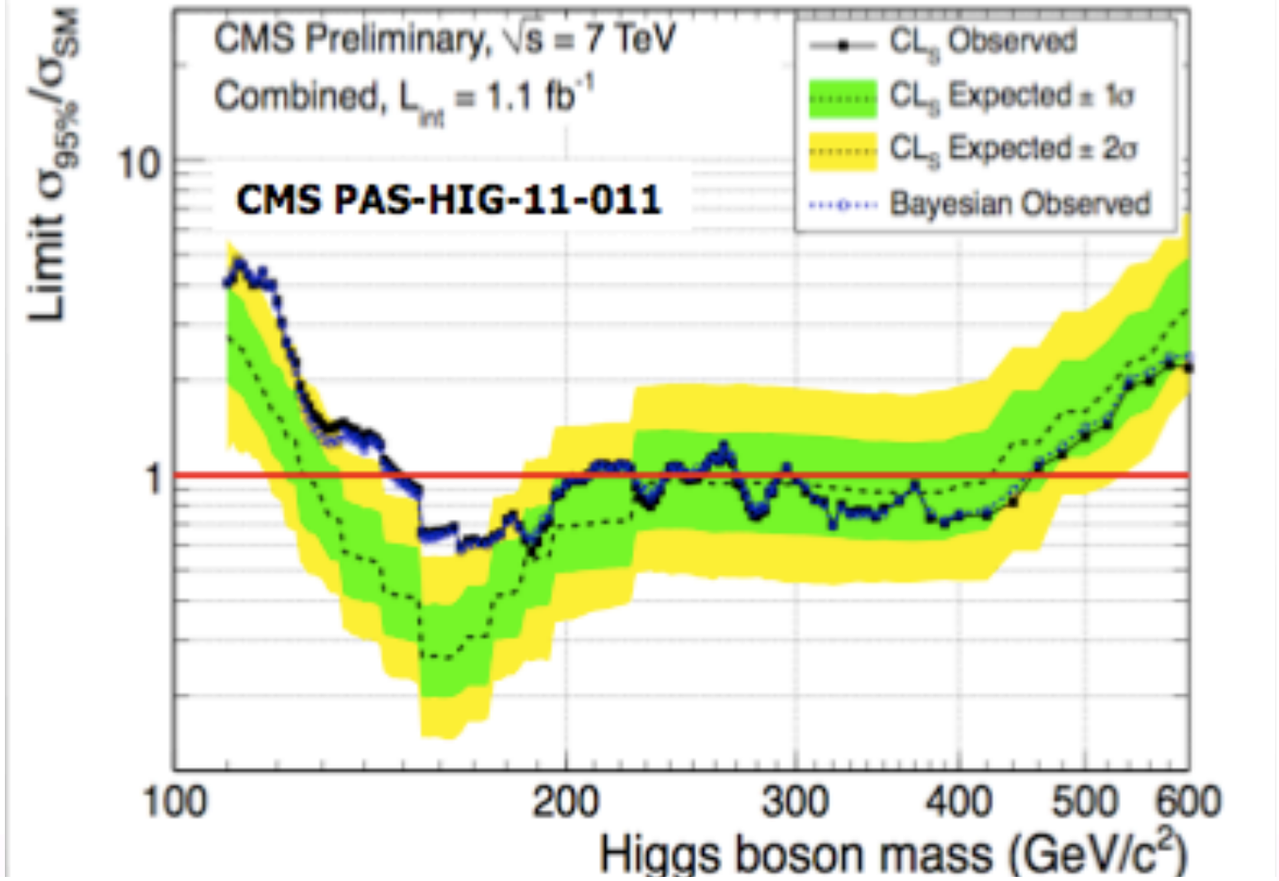
Jun 11, more than 100 people with Geiger counters to hear about correct radiation measurement

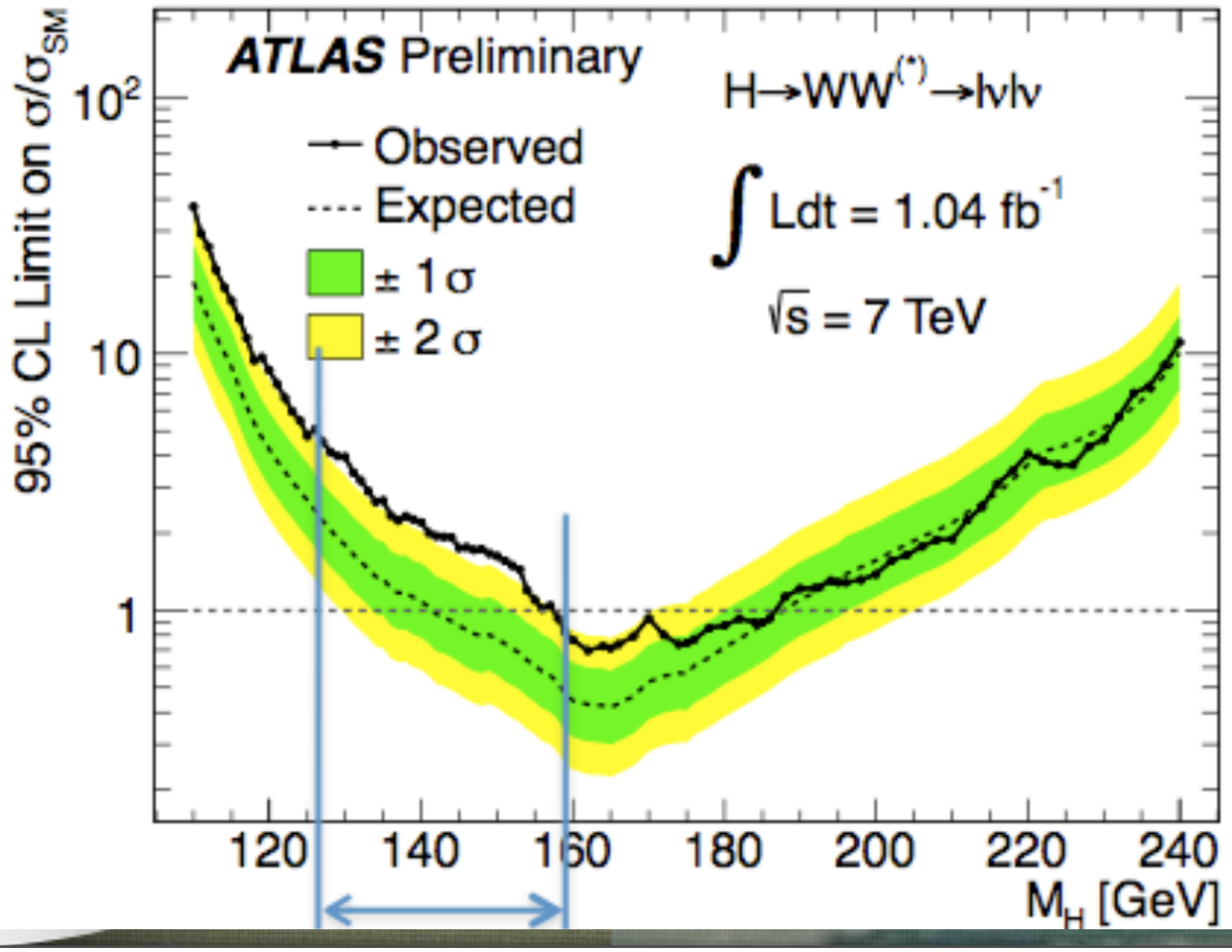
And Fukushima accident -- An example of public relation

360,000
access comic

General public forced to learn radiations

too difficult →need comic version of it.... It's me, oh well

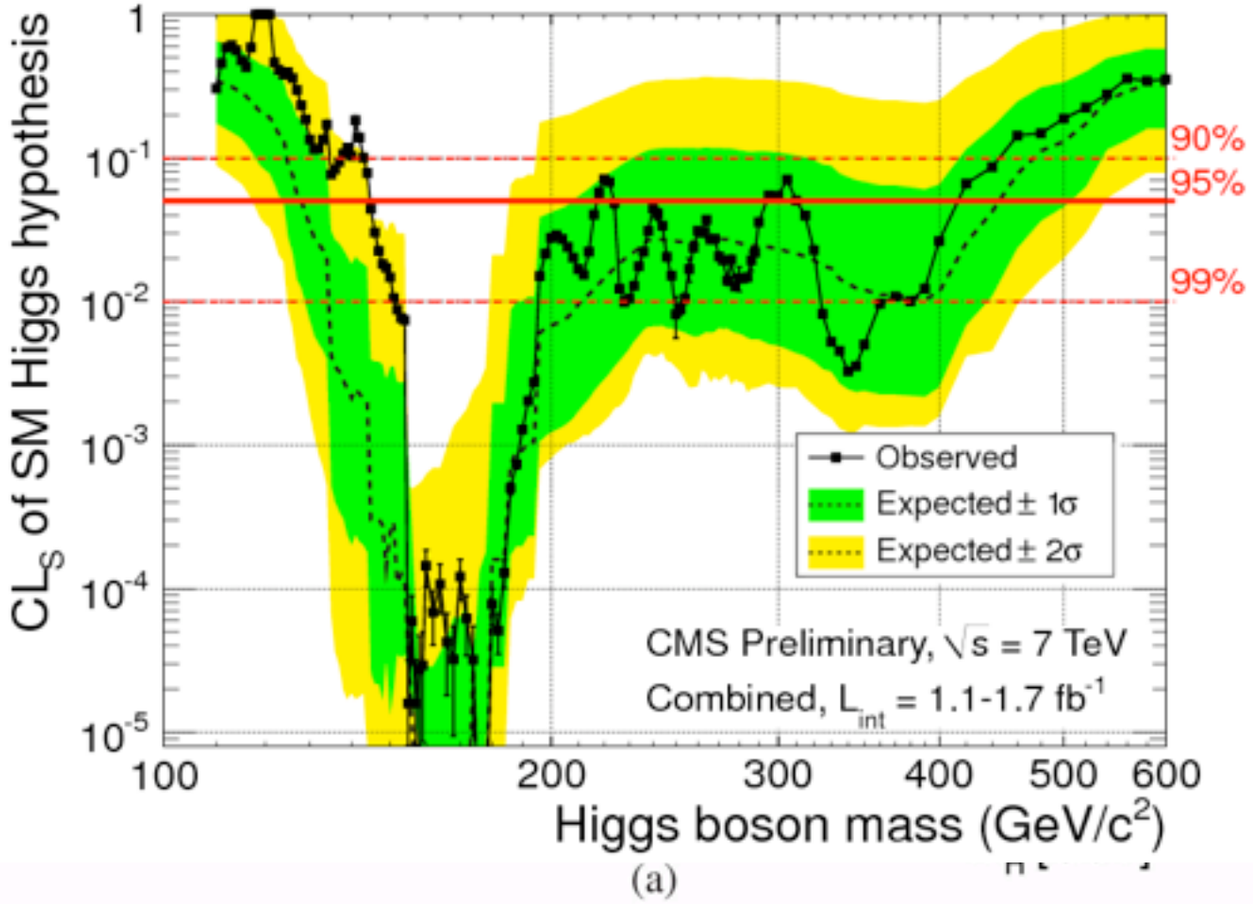




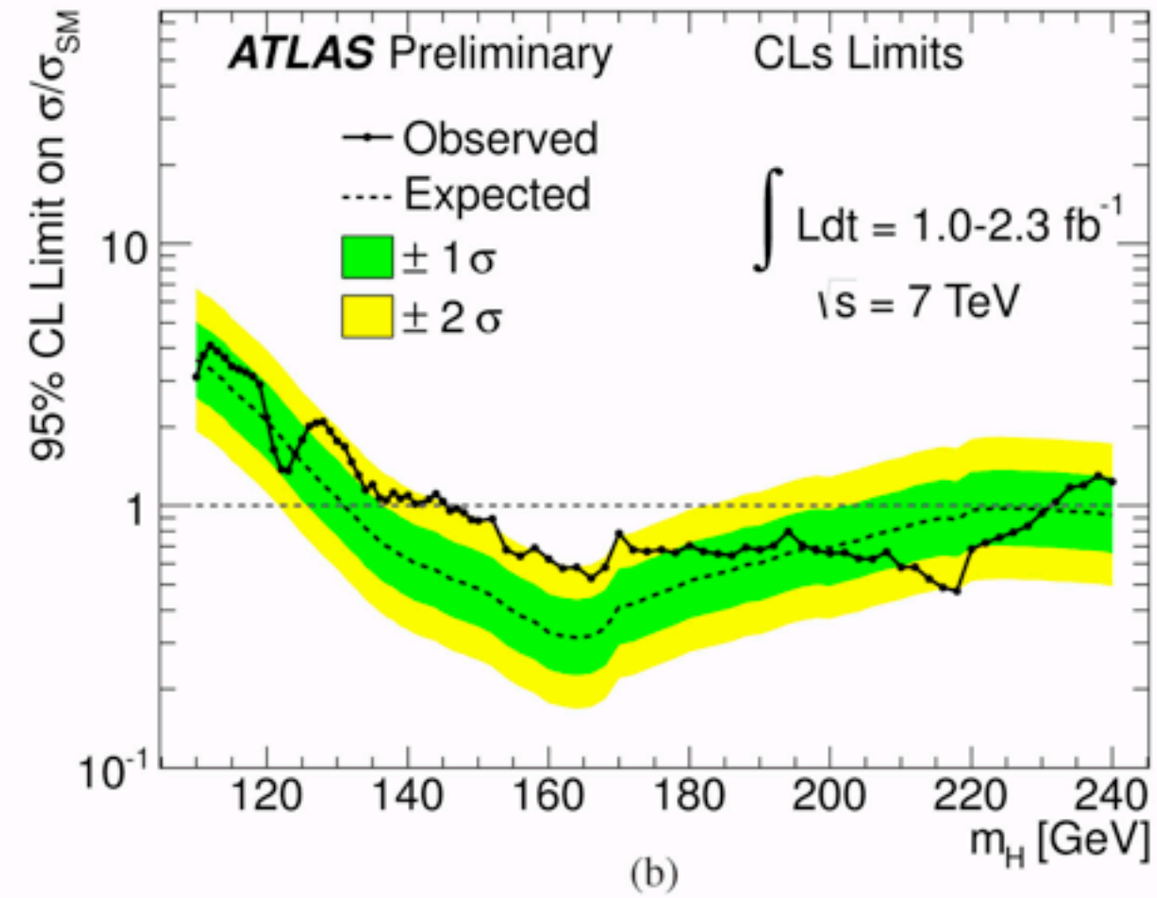
Tsunami on MSSM

EPS:broad excess between mH=128-158 GeV at 1fb-1

(・ ・ ;)



(a)



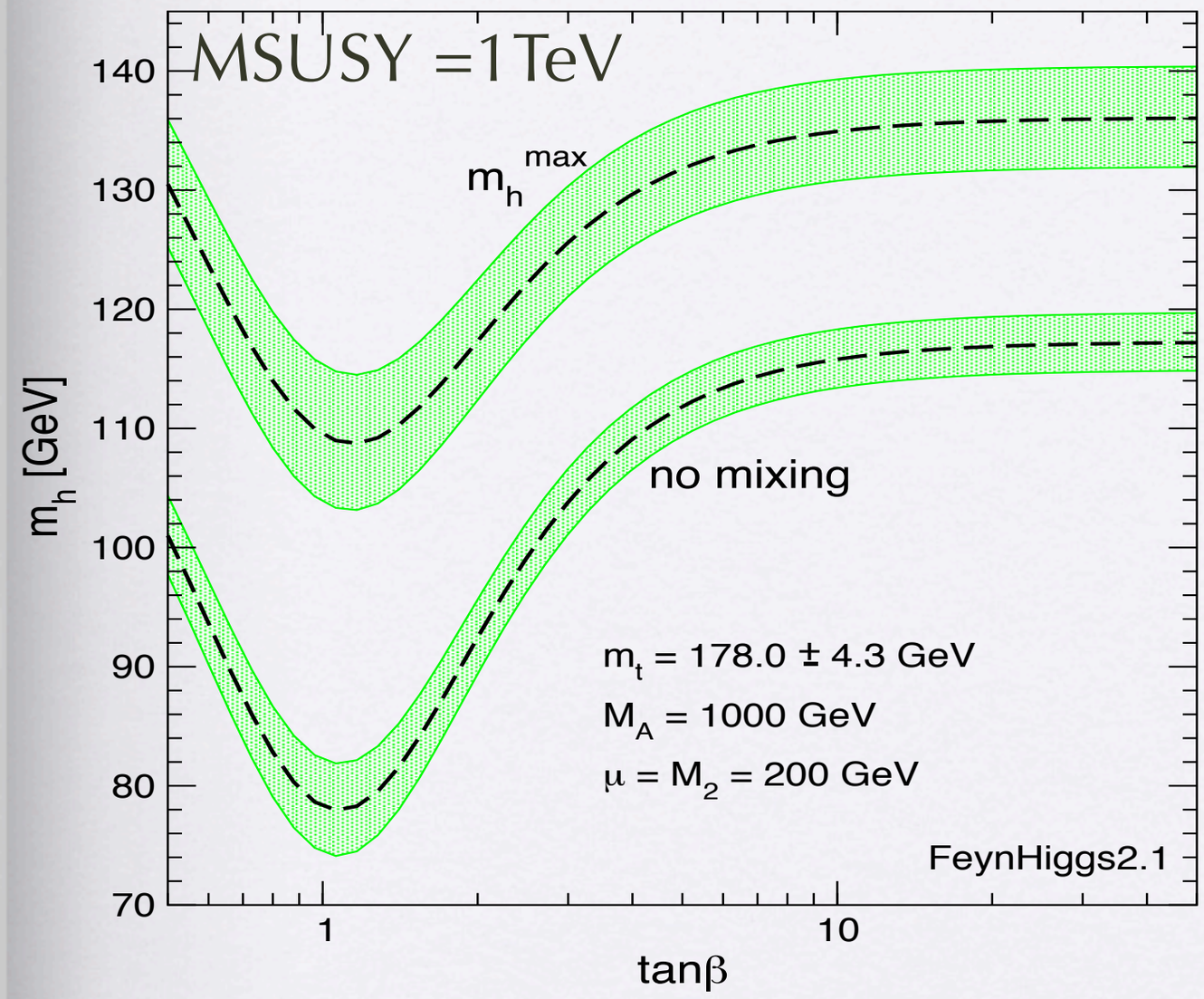
(b)

Tsunami on MSSM

EPS:broad excess between mH=128-158 GeV at 1fb-1
(・ ・ ;)

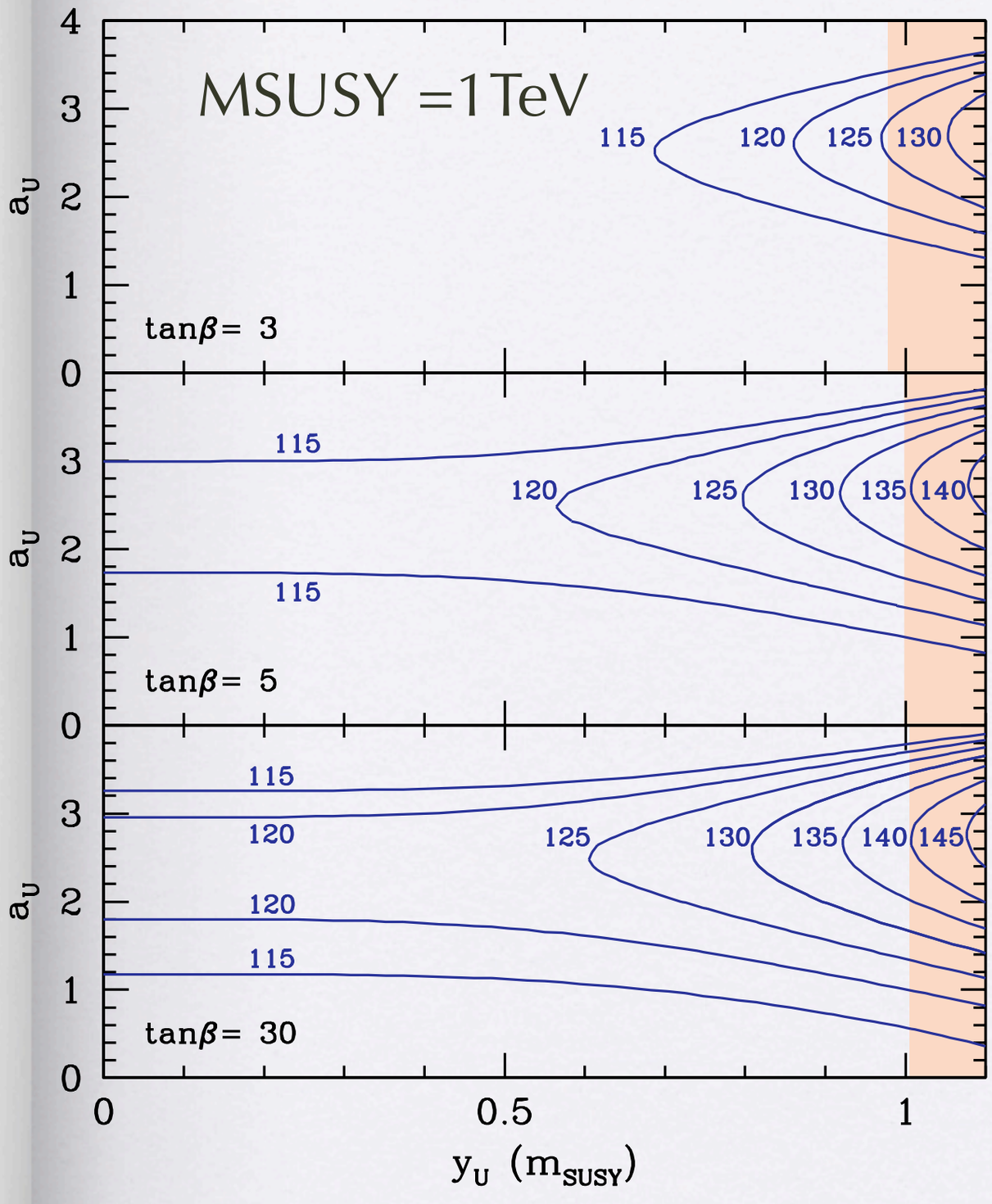
LP: the excess is less significant at 2fb^{-1}
Higgs boson above 145 GeV is excluded (^_^;)

SM Higgs mass and MSSM



- Higgs mass above 130 GeV is very difficult for MSUSY (mstop) ~1TeV
- Larger Higgs mass may be achieved for large A parameter.

SM Higgs mass and MSSM



- Higgs mass above 130 GeV is very difficult for MSUSY (mstop) ~1TeV
- Larger Higgs mass may be achieved for large A parameter.

NOTE The upper bound is fragile
ex. Asano et al 1108.2402
with additional 4th generation like particle

SUSY also has not been found yet

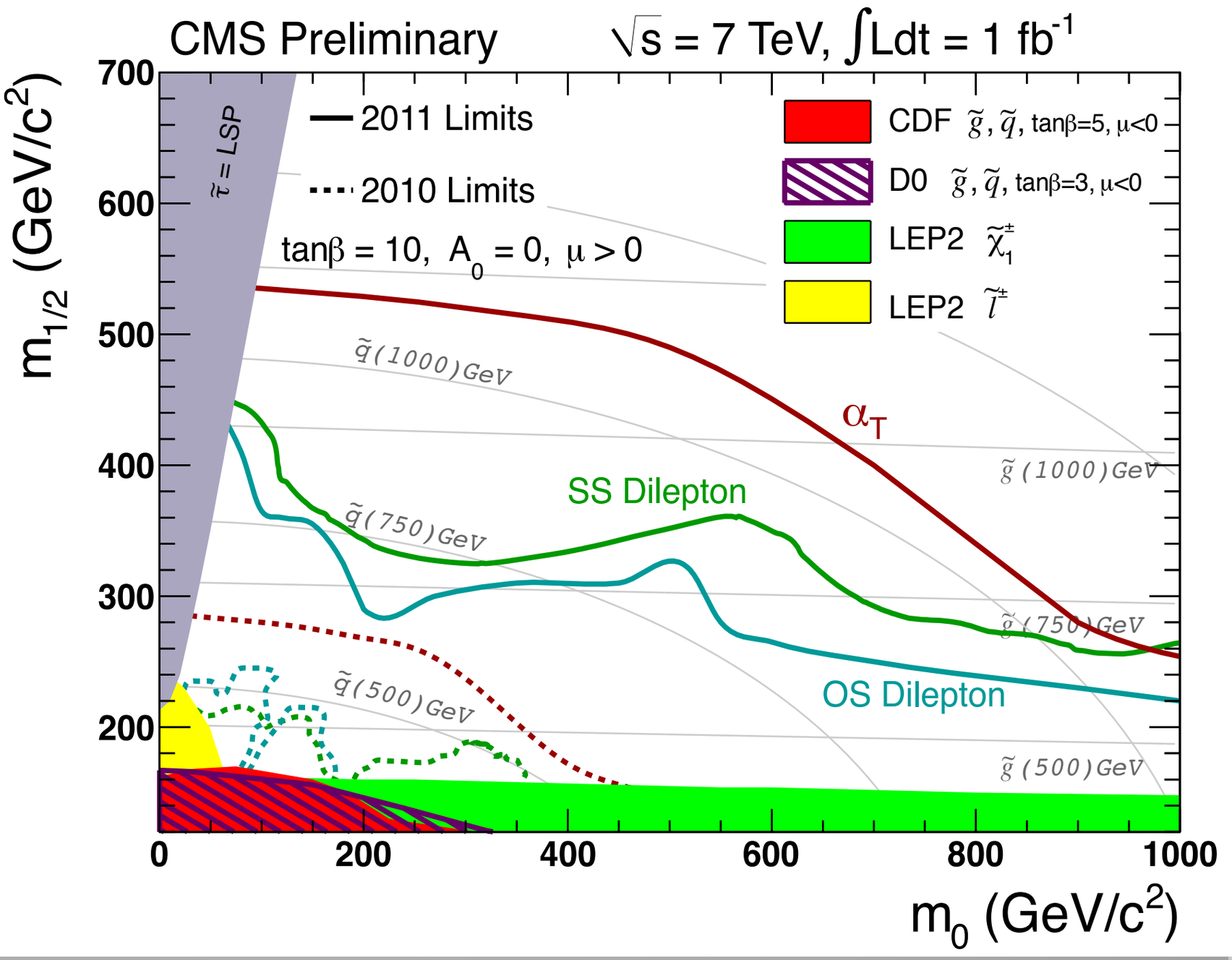
CMS at EPS

Results of three SUSY analyses completed on 2011 data (α_T , Same Sign and Opposite Sign dileptons).

CMS-SUS-11-003

CMS-SUS-11-010

CMS-SUS-11-011



Within the Constrained MSSM model we are crossing the border of excluding gluinos up to 1TeV and squarks up to 1.25TeV

“really nothing so fa ”
Why haven’t we found anything?

Because we understand QCD better now

- In 90's: We do not know how to calculate multi-jet processes at the hadron collider "I do not trust hadron collider physics" is typical attitudes in e^+e^-collider funs in 90's

- Progress in "Matching" and NLO

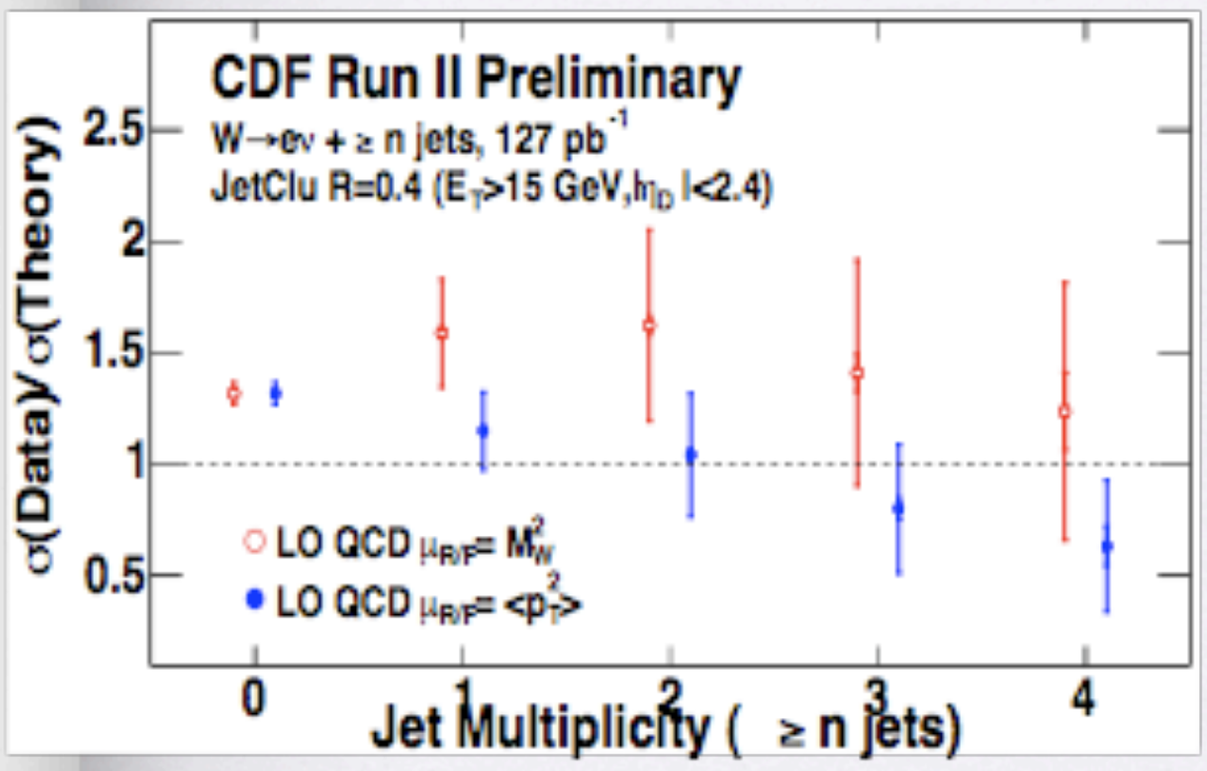
- We do not "discover" much until we reach **the point**. (unlike the era of SPS)

photo 1972

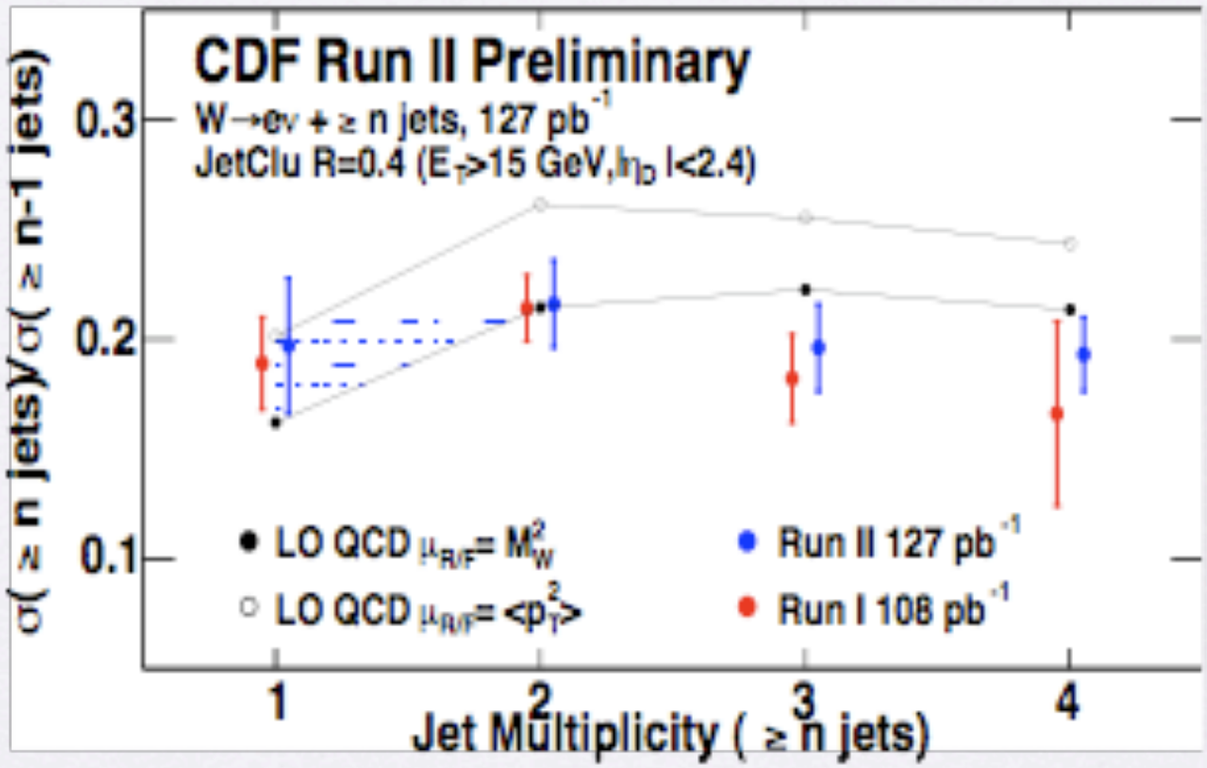
W+jets (leading SUSY BG at 7TeV)

Data vs Theory in 2003

Data vs Theory

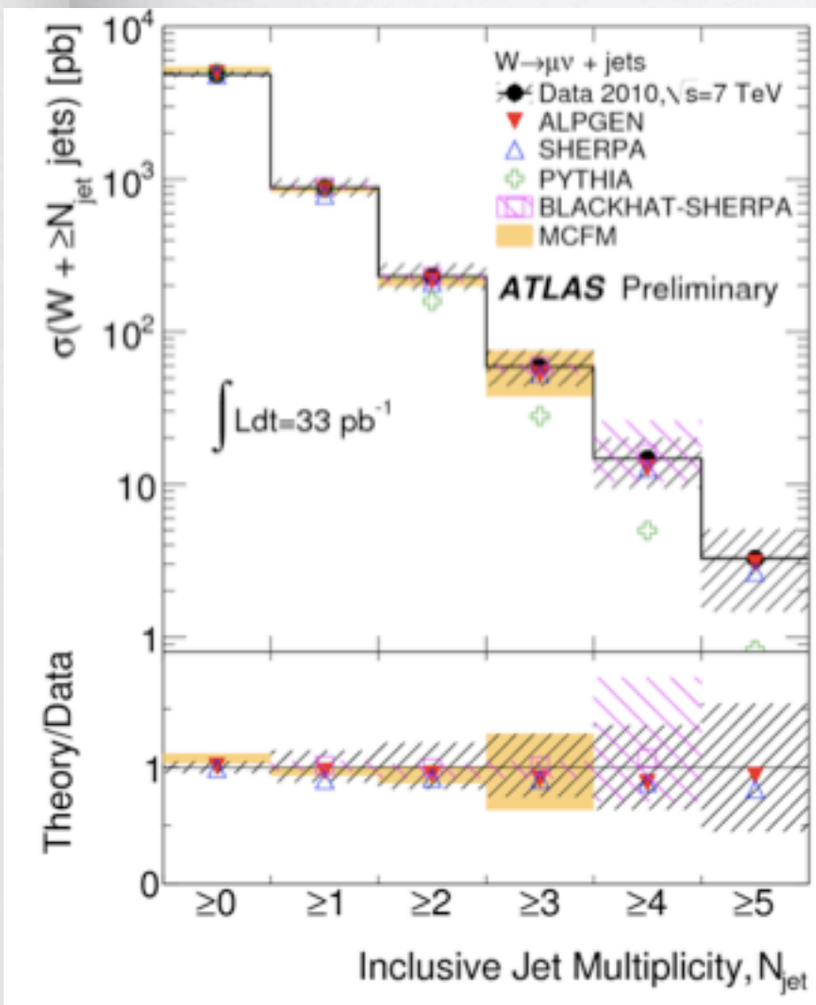


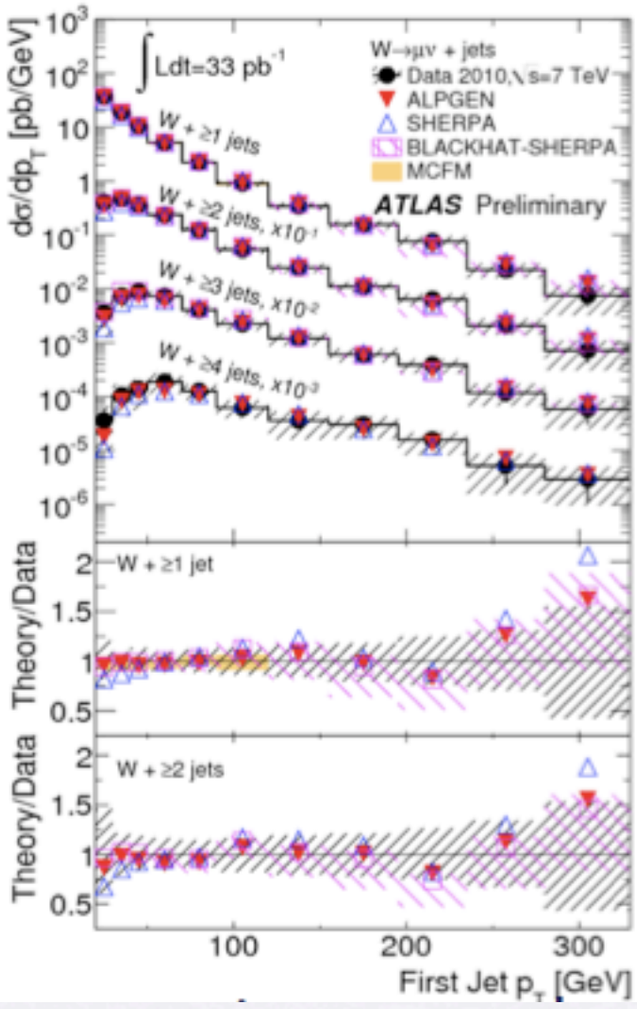
Ratio of Cross-sections

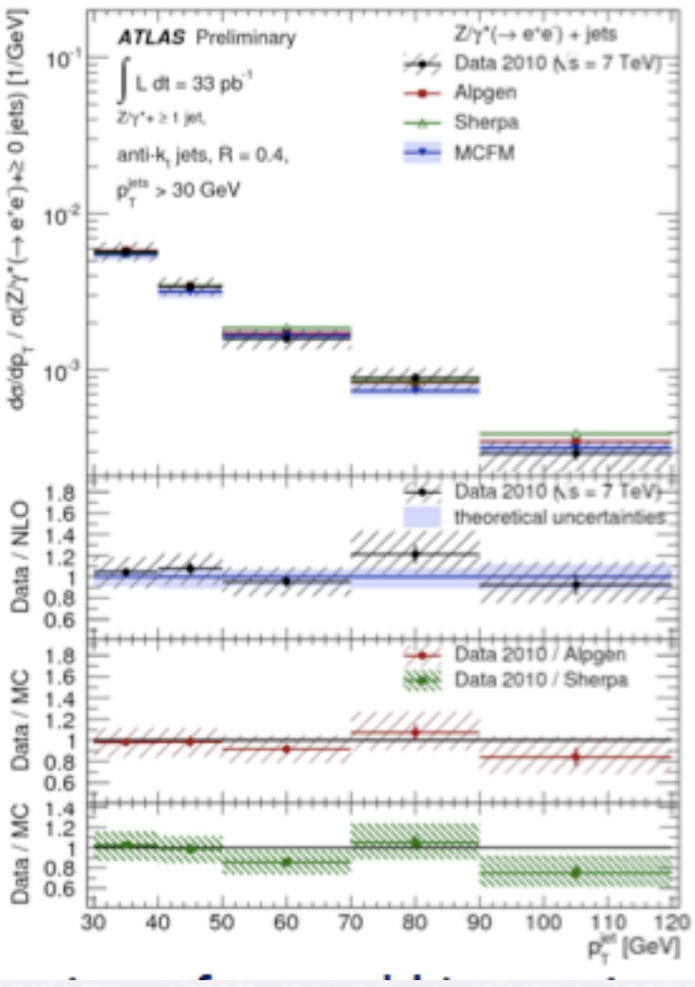


W+jets (leading SUSY BG at 7TeV)

Data vs Theory in 2011







Background and discovery

- Jets + W, Z and Jets + tt distribution at LHC are consistent with simulation thanks to the multi-jet ME and matching (Sherpa, Alpgen, Madgraph,...) and various NLO generators.

- On the other hand, once you apply **cuts, cuts, cuts**, to estimate the backgrounds in the signal region, there are problem. We are not in the level to predict the tail where only 1/1000 of total events exists.

- Therefore some background is estimated from the control region, for example the tail of missing ET from Z->ee and so on.

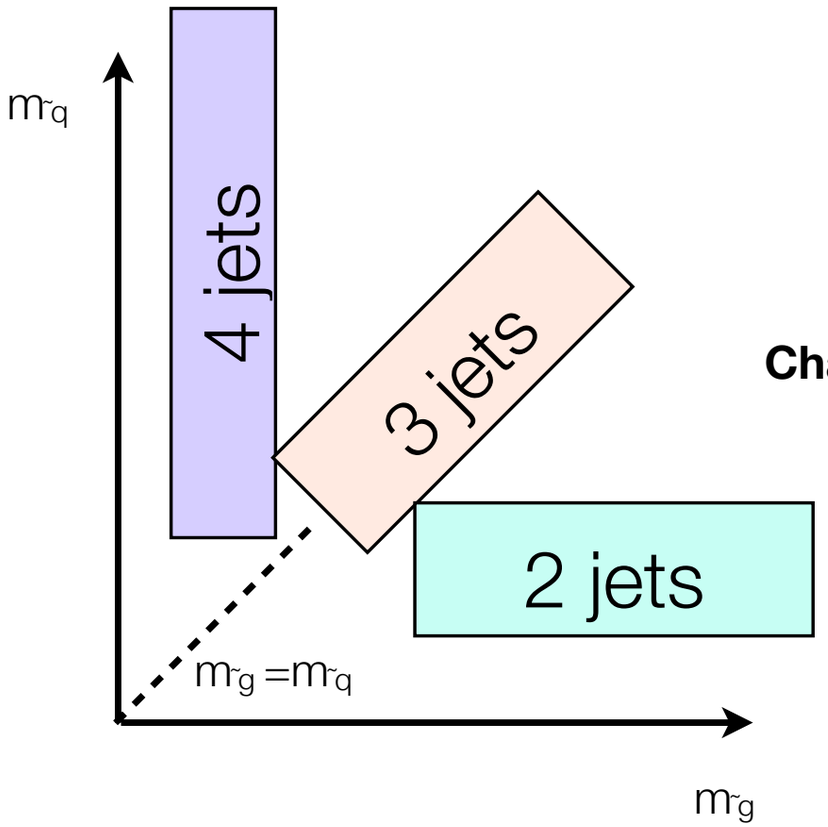
- This is where some Higgs and SUSY searches are. (ex: H-> WW)

SUSY search and measurement

Now and future

Event selection

- Depending on the SUSY mass hierarchy, different production processes favoured ($\tilde{g}\tilde{g}, \tilde{g}\tilde{q}, \tilde{q}\tilde{q}$)
  - Signal regions optimised to maximise sensitivity to different production processes



	Signal Region	≥ 2 jets	≥ 3 jets	≥ 4 jets	High mass
Trigger requirements	$E_{\mathrm{T}}^{\mathrm{miss}}$	> 130	> 130	> 130	> 130
	Leading jet p_{T}	> 130	> 130	> 130	> 130
Channel definition	Second jet p_{T}	> 40	> 40	> 40	> 80
	Third jet p_{T}	–	> 40	> 40	> 80
	Fourth jet p_{T}	–	–	> 40	> 80
Reduce QCD	$\Delta\phi(\mathrm{jet}, E_{\mathrm{T}}^{\mathrm{miss}})_{\mathrm{min}}$	> 0.4	> 0.4	> 0.4	> 0.4
	$E_{\mathrm{T}}^{\mathrm{miss}}/m_{\mathrm{eff}}$	> 0.3	> 0.25	> 0.25	> 0.2
Enhance signal	m_{eff} [GeV]	> 1000	> 1000	> 500/1000	> 1100

$$m_{eff} = \sum_{i=1}^{n} |\vec{p}_T^{\,jet\ i}| + E_T^{miss}$$

In my view, this is THE BEST way to presenting data

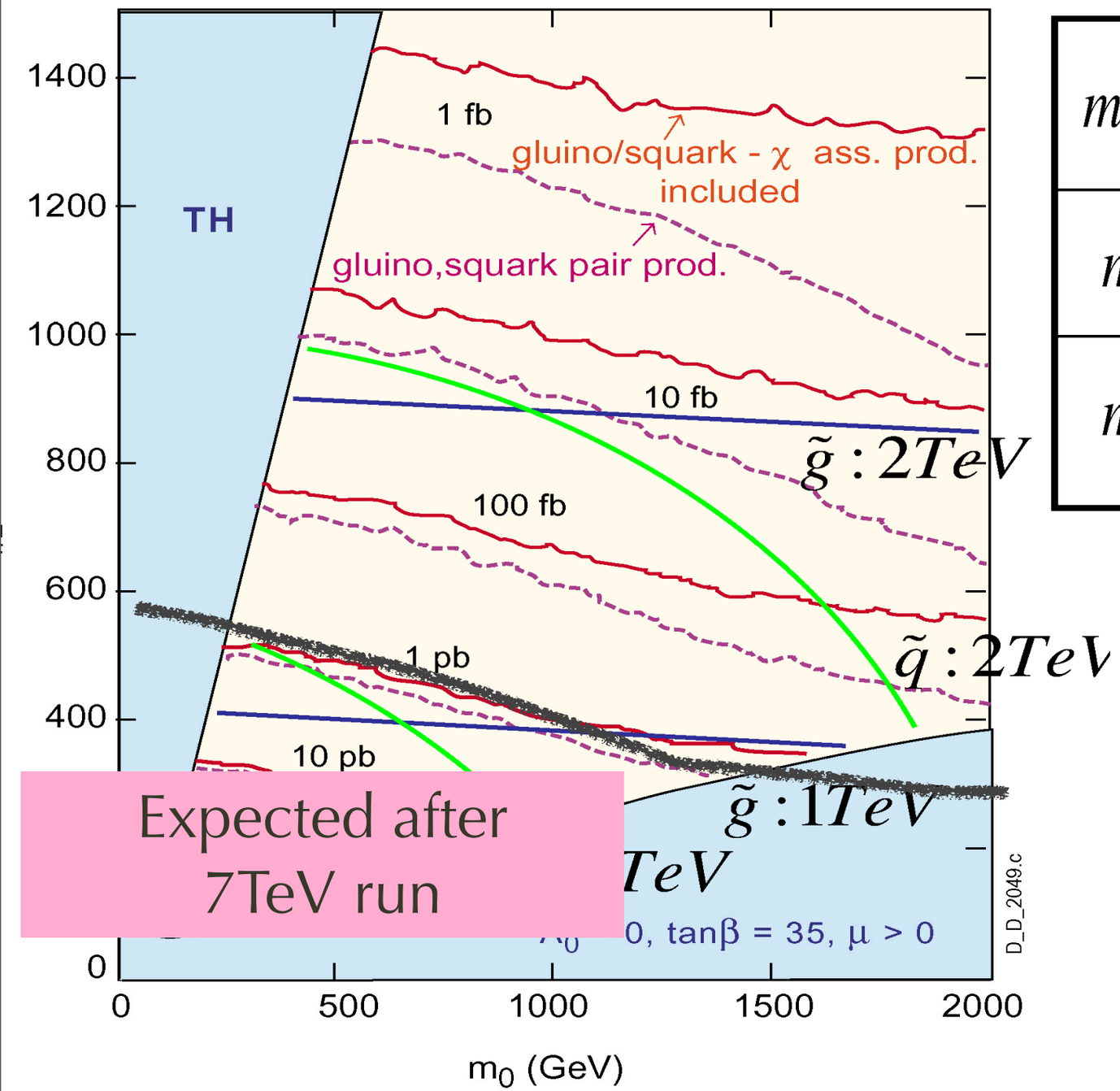
Results

Process	Signal Region				
	≥ 2-jet	≥ 3-jet	≥ 4-jet, m_{eff} > 500 GeV	≥ 4-jet, m_{eff} > 1000 GeV	High mass
Z/γ+jets	32.5 ± 2.6 ± 6.8	25.8 ± 2.6 ± 4.9	208 ± 9 ± 37	16.2 ± 2.1 ± 3.6	3.3 ± 1.0 ± 1.3
W+jets	26.2 ± 3.9 ± 6.7	22.7 ± 3.5 ± 5.8	367 ± 30 ± 126	12.7 ± 2.1 ± 4.7	2.2 ± 0.9 ± 1.2
$t\bar{t}$+ single top	3.4 ± 1.5 ± 1.6	5.6 ± 2.0 ± 2.2	375 ± 37 ± 74	3.7 ± 1.2 ± 2.0	5.6 ± 1.7 ± 2.1
QCD jets	0.22 ± 0.06 ± 0.24	0.92 ± 0.12 ± 0.46	34 ± 2 ± 29	0.74 ± 0.14 ± 0.51	2.10 ± 0.37 ± 0.83
Total	62.3 ± 4.3 ± 9.2	55 ± 3.8 ± 7.3	984 ± 39 ± 145	33.4 ± 2.9 ± 6.3	13.2 ± 1.9 ± 2.6
Data	58	59	1118	40	18
excluded σx acc (fb)	24	30	477	32	17

upper limit of each search channel

- No discrepancy with respect to SM predictions.
- The result is interpreted as a 95% CL exclusion limit on effective cross sections using a profile likelihood ratio approach following the CLs prescriptions.
- Analysis giving best expected limit used in each point.

14TeV projection



Expected after 7TeV run

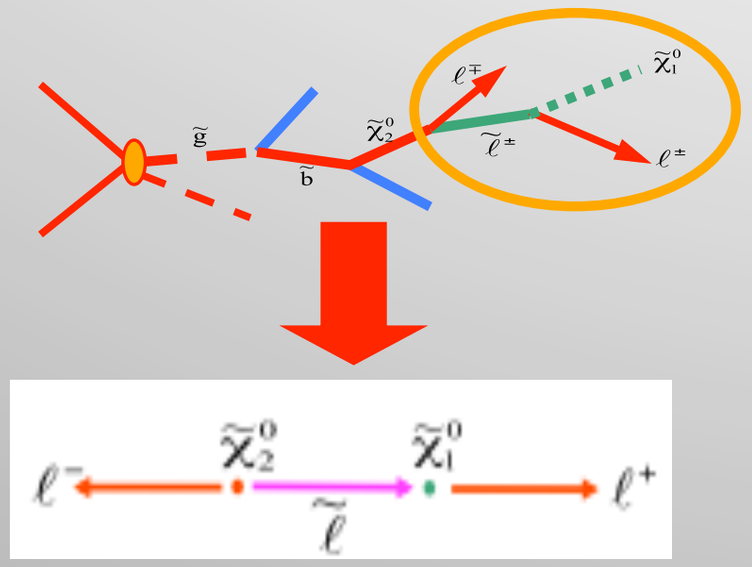
$m(\tilde{q}) = m(\tilde{g}) = 0.5TeV$	σ ～100pb $\tilde{g}\tilde{g}$ がmain
$m(\tilde{q}) = m(\tilde{g}) = 1TeV$	σ ～3pb
$m(\tilde{q}) = m(\tilde{g}) = 2TeV$	σ ～20fb $\tilde{u}\tilde{u},\tilde{u}\tilde{d}$ がmain

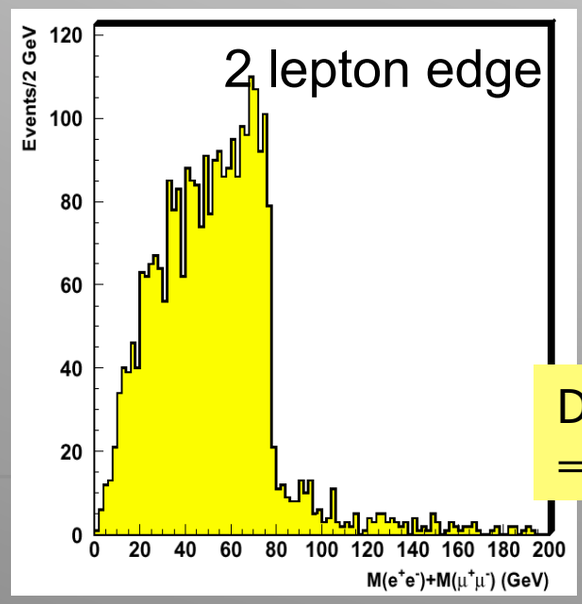
- 7TeV run excluded significant parameter space
- production at 14TeV would be 1 pb or less. significantly limits statistics at 14TeV run already.

Sparticle Detection & Reconstruction

Mass precision for a favorable benchmark point at the LHC
LCC1~ SPS1a~ point B'

m_0=100 GeV
$m_{1/2}$= 250 GeV
A_0=-100
tanβ = 10
sign(μ)=+





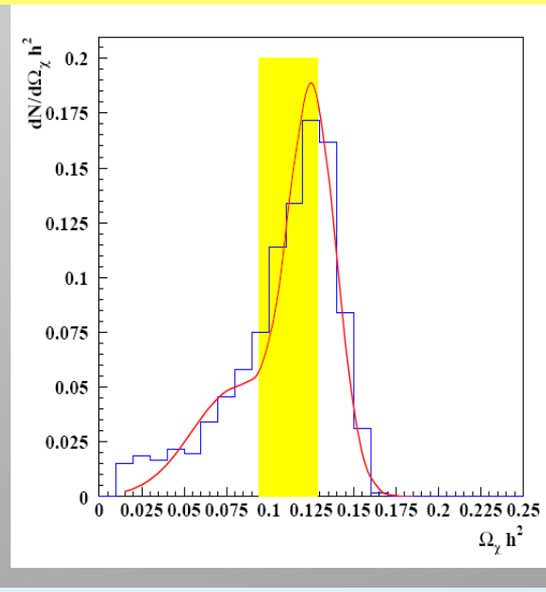
D. Miller et al
⇒Use shapes

25

hep-ph/0508198
100 fb^{-1}, 14 TeV

GeV	LHC
$\Delta m_{\tilde{\chi}_1^0}$	4.8
$\Delta m_{\tilde{\chi}_2^0}$	4.7
$\Delta m_{\tilde{\chi}_4^0}$	5.1
$\Delta m_{\tilde{l}_R}$	4.8
$\Delta m_{\tilde{\ell}_L}$	5.0
Δm_{τ_1}	5-8
$\Delta m_{\tilde{q}_L}$	8.7
$\Delta m_{\tilde{q}_R}$	7-12
$\Delta m_{\tilde{b}_1}$	7.5
$\Delta m_{\tilde{b}_2}$	7.9
$\Delta m_{\tilde{g}}$	8.0

Lightest neutralino → Dark Matter?
Fit SUSY model parameters to the measured SUSY particle masses to extract $\Omega\chi h^2$ ⇒ O(10%) for LCC1



This point and much more of the CMSSM space is ruled out
What can LHC still say on DM?

SUSY mass determination using jets+ 2 lepton channel

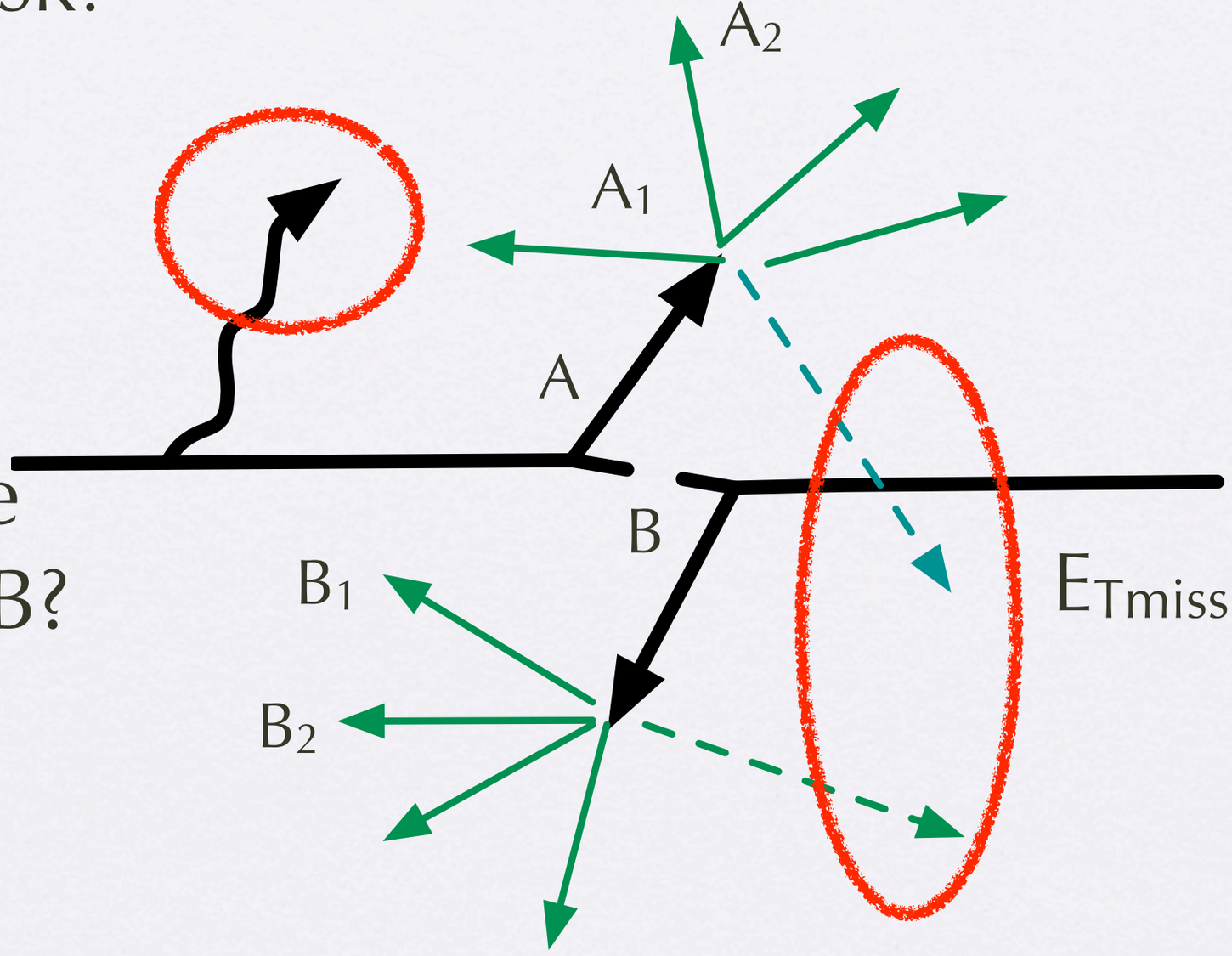
- production cross section is determined by squark gluino mass
- Branching ration into the second lightest neutralino 30% , lepton branch 6~20%→ total 2~6%.
- $30fb^{-1}$ x 1pb =30000-> **600 events(2% branch) are not enough** to determine EW SUSY particles masses precisely
- **Need full use of hadronic channels to determine SUSY scale when it is discovered.**

Combinatorial background in hadronic channel

USE MT2~mass of parents

2) ISR; Which jet comes from ISR?

1) jets are from A or B?



Combinatorial background in hadronic channel

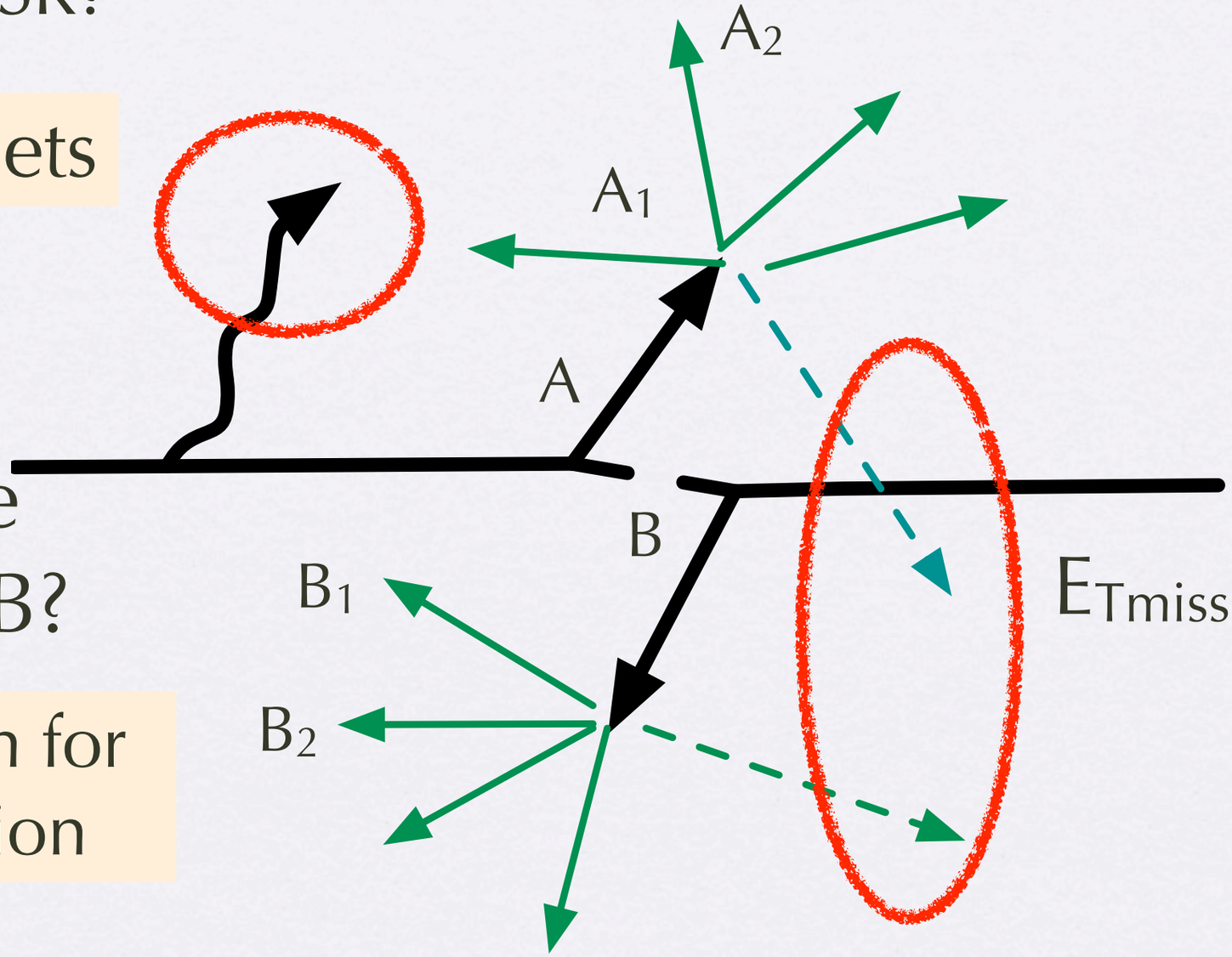
USE MT2~mass of parents

2) ISR; Which jet comes from ISR?

use part of the jets

1) jets are from A or B?

Take minimum for jet combination

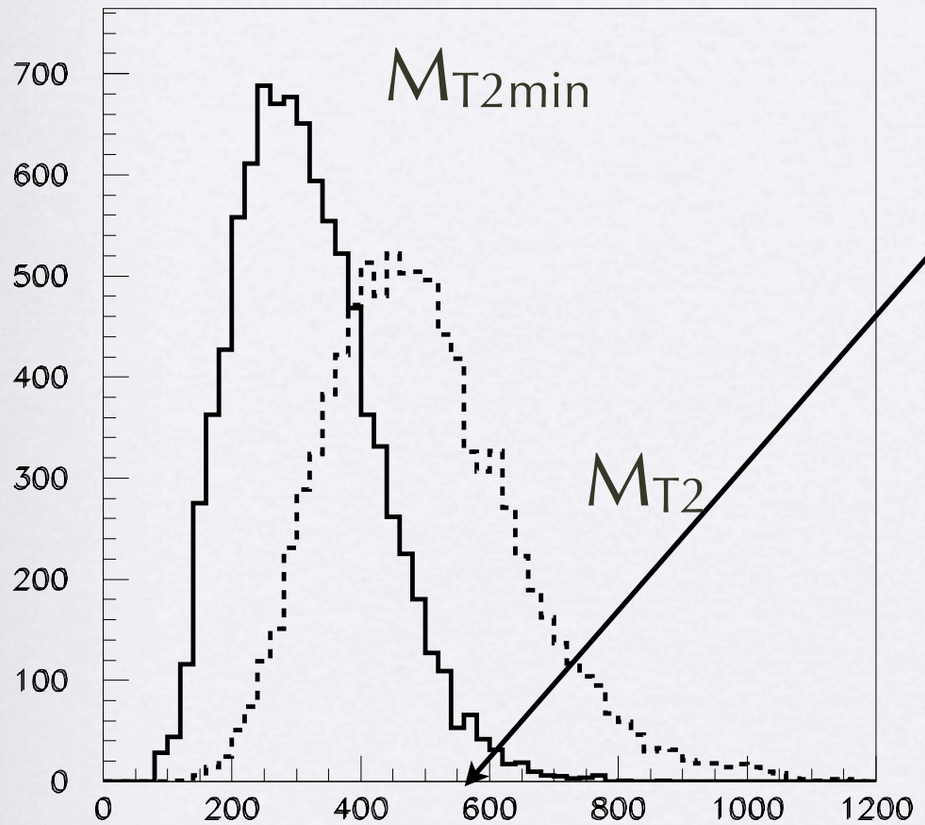


MT2 and mass reconstruction

$$m_{T2}(\mathbf{p}_T^{vis(1)},\, m_{vis}^{(1)},\, \mathbf{p}_T^{vis(2)},\, m_{vis}^{(2)},\, m_\chi) \equiv \min_{\{\mathbf{p}_T^{\chi(1)}+\mathbf{p}_T^{\chi(2)}=-\mathbf{p}_T^{vis(1)}-\mathbf{p}_T^{vis(2)}\}} \left[\max\{m_T^{(1)}, m_T^{(2)}\}\right],$$

7TeV 100fb^{-1}

mgl=558GeV mul=825 GeV



input gluino mass

M_{T2} for multijet final state = minimization for all jet combination

M_{T2min}=ISR removal ~remove one jet from the minimization (among 5 leading jets)

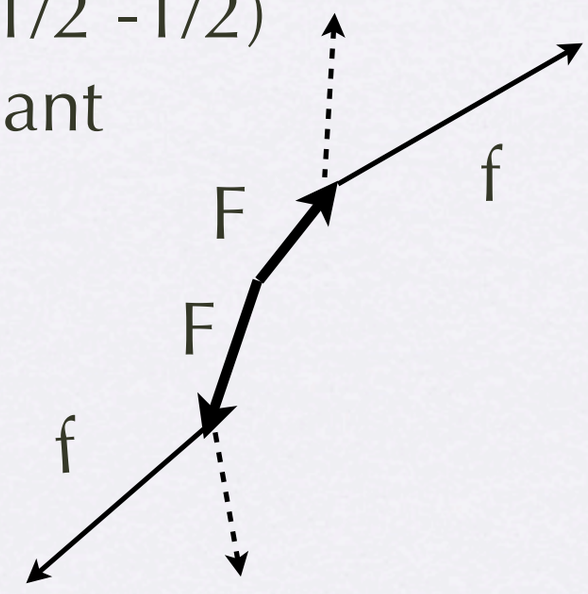
Nojiri Sakurai 2010

Reconstruction of (squark /gluino mass -LSP mass) may be possible

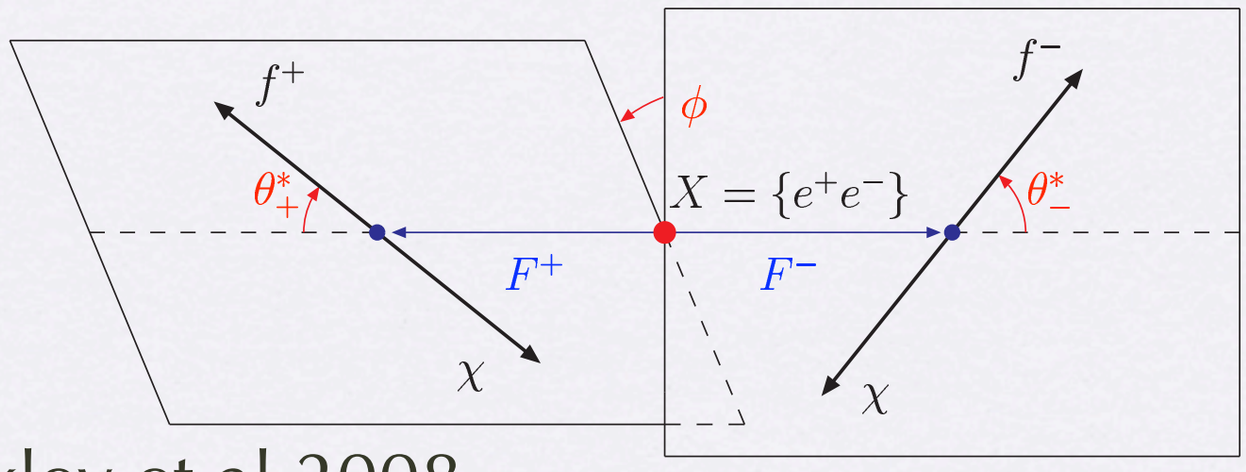
How about spin measurements

- in Jet +2 lepton channel spin effect in the inv. mass distribution, able to distinguish SUSY vs "Same spin partner" models (such as LHT, UED)
- jet channel: there are jet ID problem, but jets from two body decay of quark partner is easy to identify becuase of the PT
- If the interaction of quark partner is chiral, there are visible spin effect

polarization
(1/2 1/2) **or** (-1/2 -1/2)
is dominant

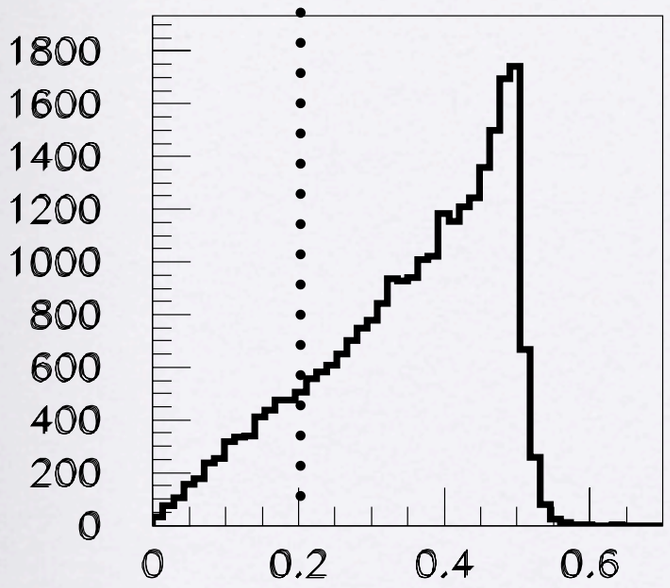


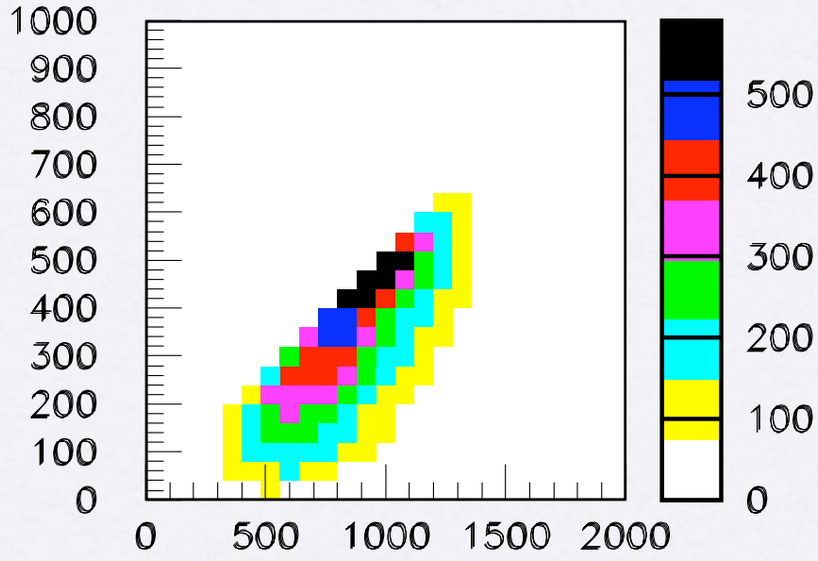
Azimuthal angle correlation
(1/2,1/2) **and** (-1/2,-1/2)
amplitude is same order



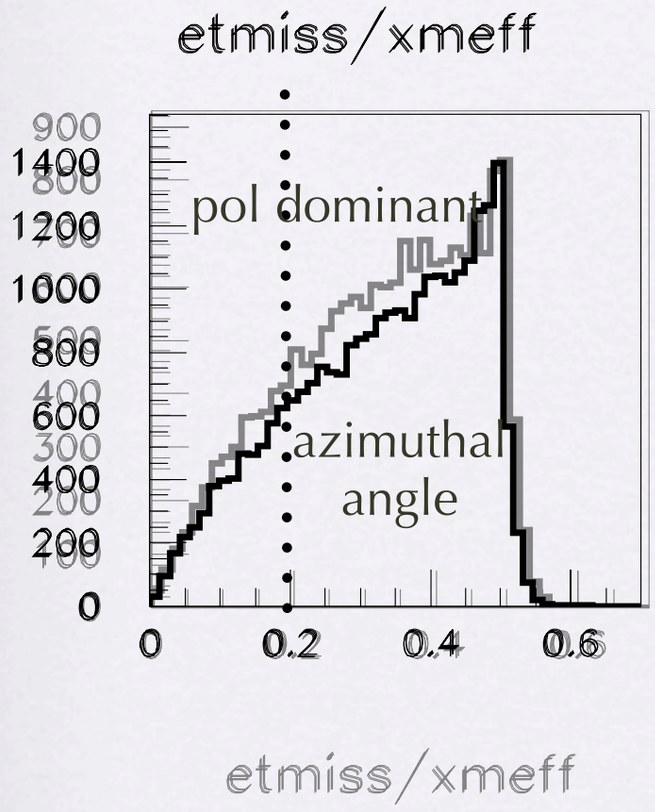
Buckley et al 2008

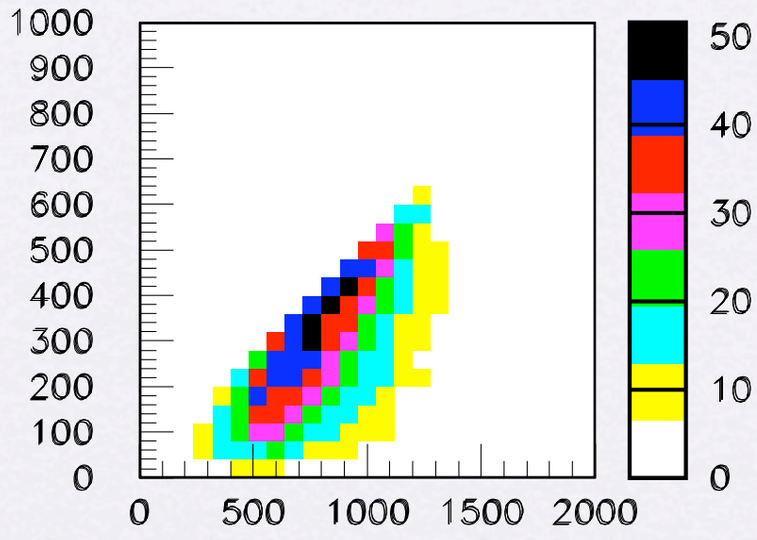
The jet level distribution for pp→$U_R U_R$→ uu χχ





No spin correlation
(Madgraph 2 by 2
→pythia)





with spin correlation
Madgraph
2 by 4

Nojiri, J. Shu JHEP 2011

SUSY study in 2012

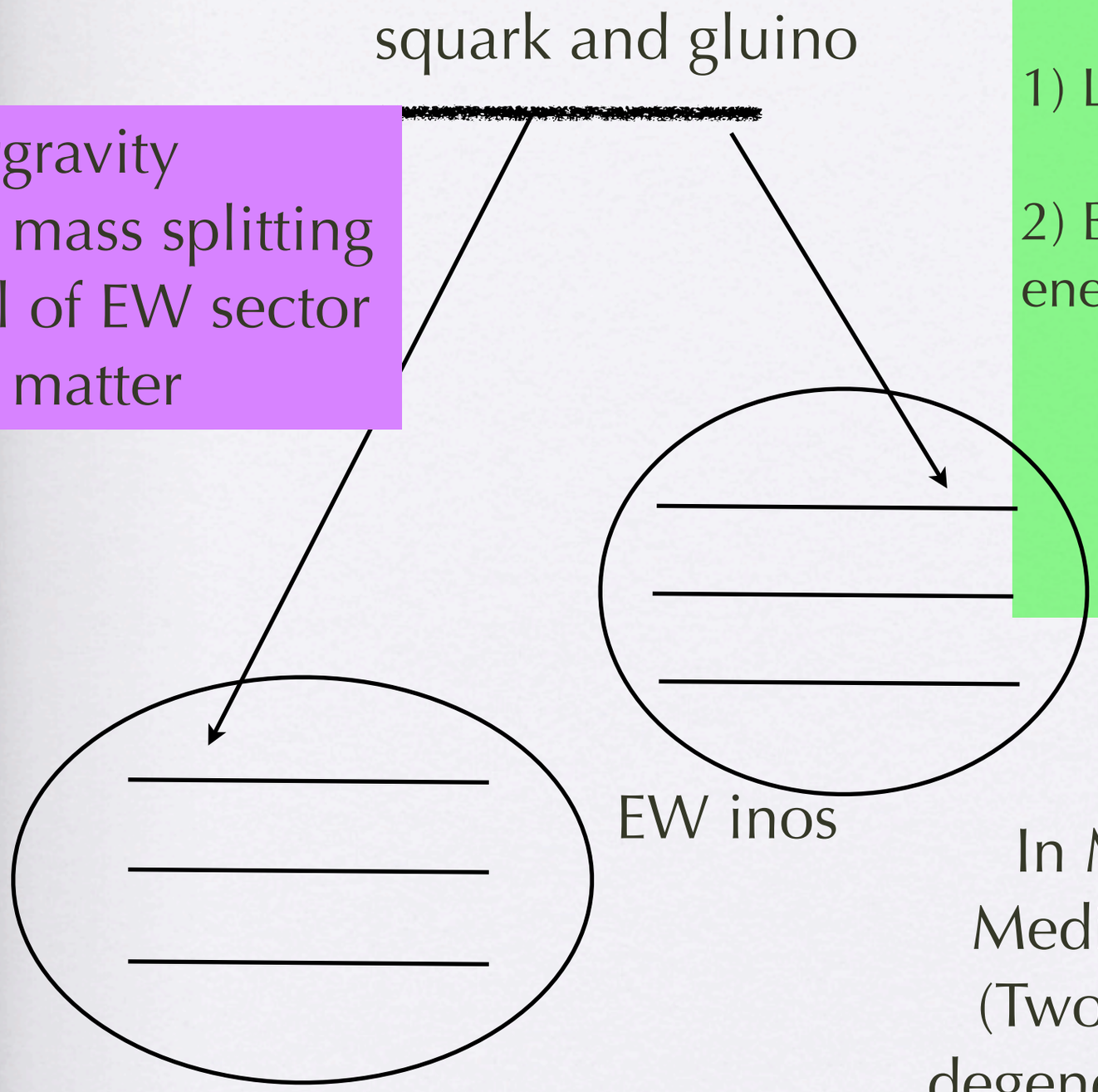
$1fb^{-1} \rightarrow 5fb^{-1}$ this year, probably reaching up to 1.2TeV, and not much extension to higher mass at 7TeV in 2012

It will be **High energy "high luminosity" frontier**→better understanding of W, top productions → increasing discovery potential in the **SM-MSSM overlapping area**.

NOTE: Current study relies on a few high pT leading jets arising from large mass splitting between colored SUSY particles and dark matter. Especially It does not cover degenerate SUSY mass spectrum

Mass spectrum and signal

Supergravity
Large mass splitting
Detail of EW sector
is not matter



If degenerate

1) LSP is not toorelativistic

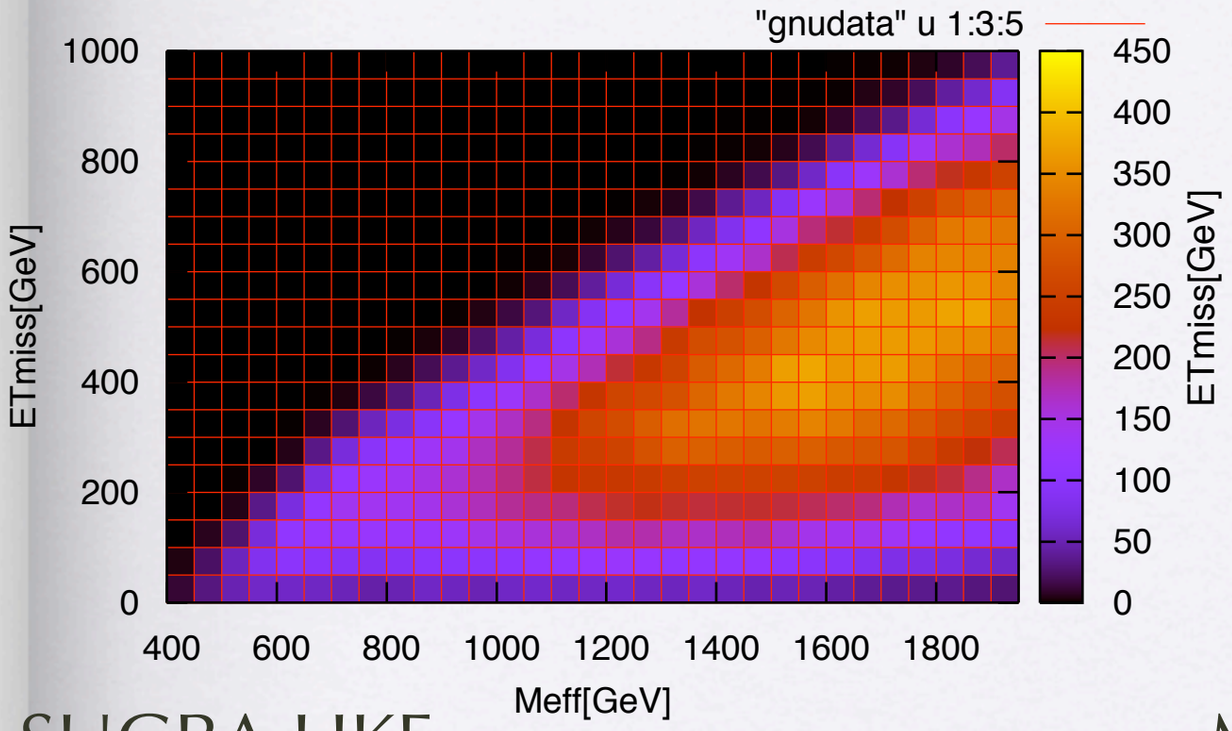
2) Both cross section and visible energy are small,, overlap with SM

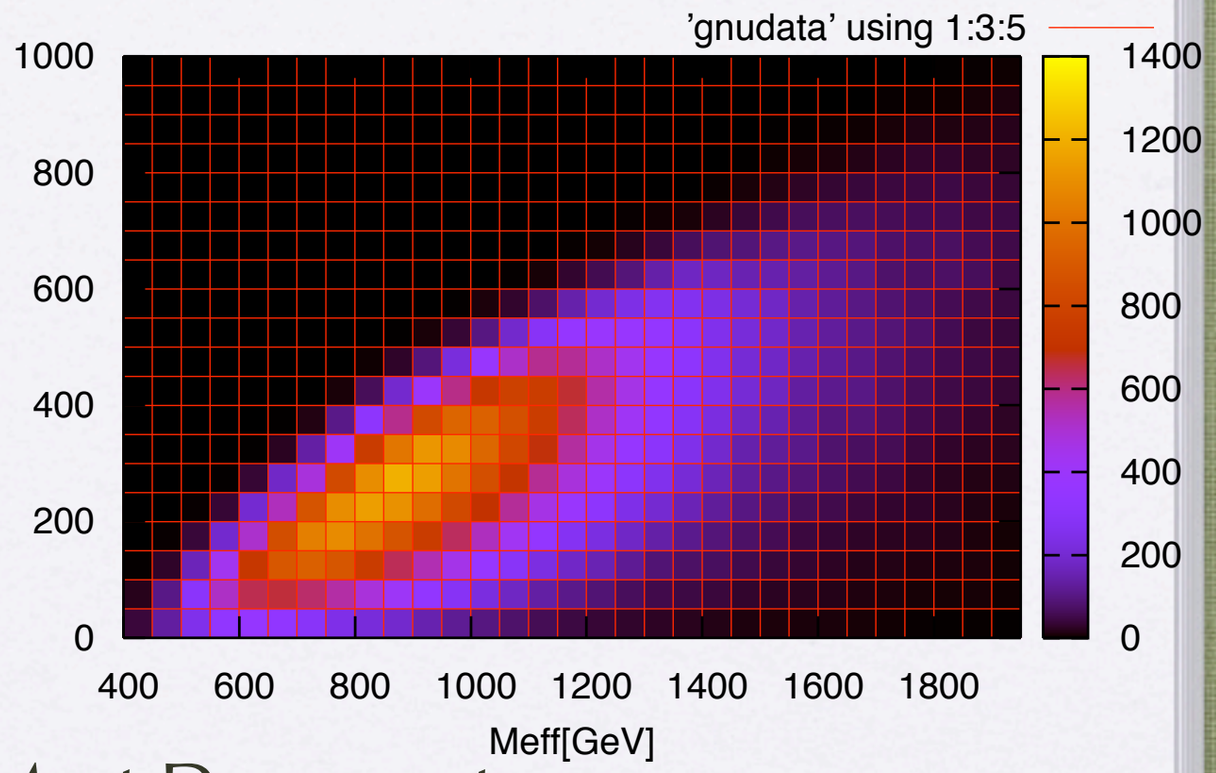
3) Difficult to identify the parents of the jet

In Mixed Modulus Anomaly Mediation model (KKLT model, (Two source of SUSY breaking) degenerate mass spectrum possible

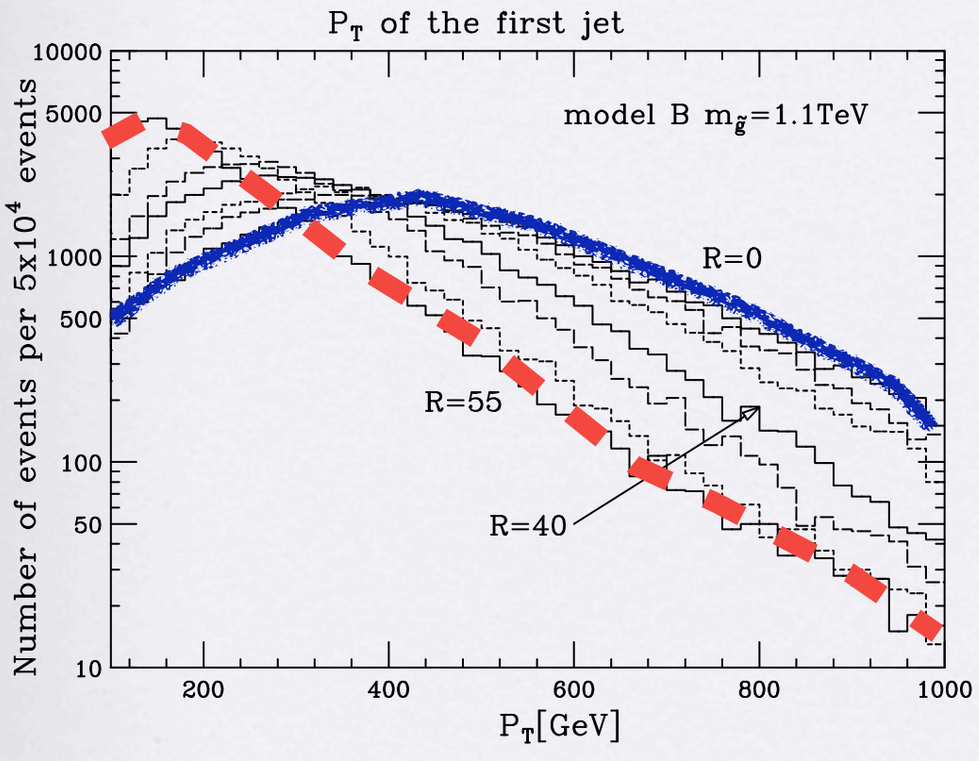
signal distribution of degenerate case. No way if mLSP> 0.7 m(squark) ??

M. N. and Kawagoe **Phys.Rev.D74:115011,2006.**



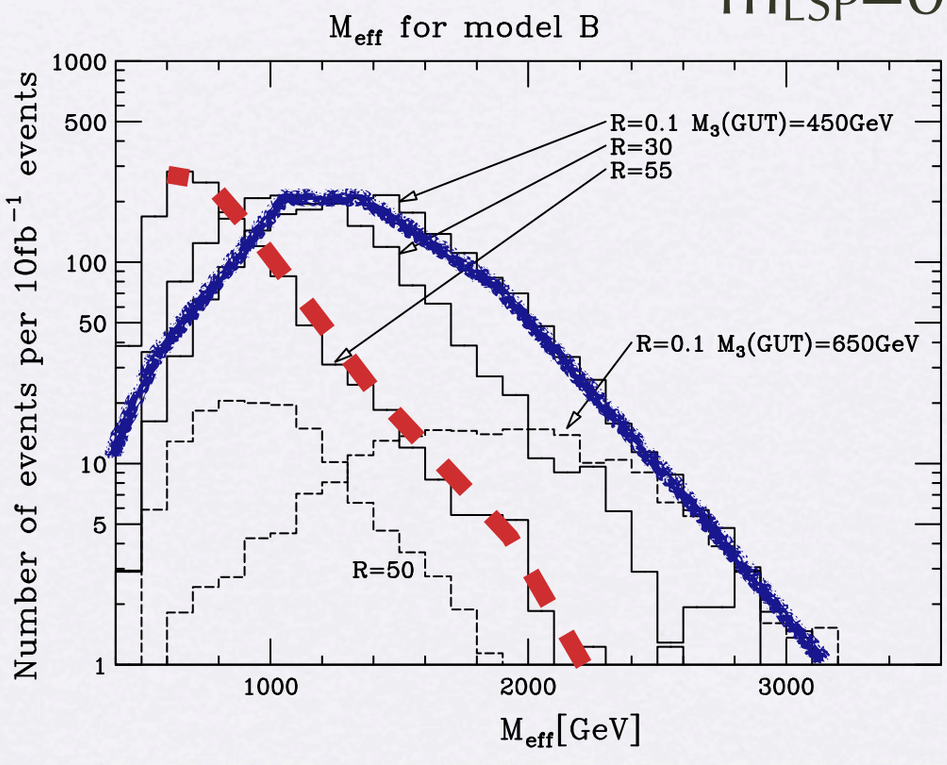


SUGRA LIKE



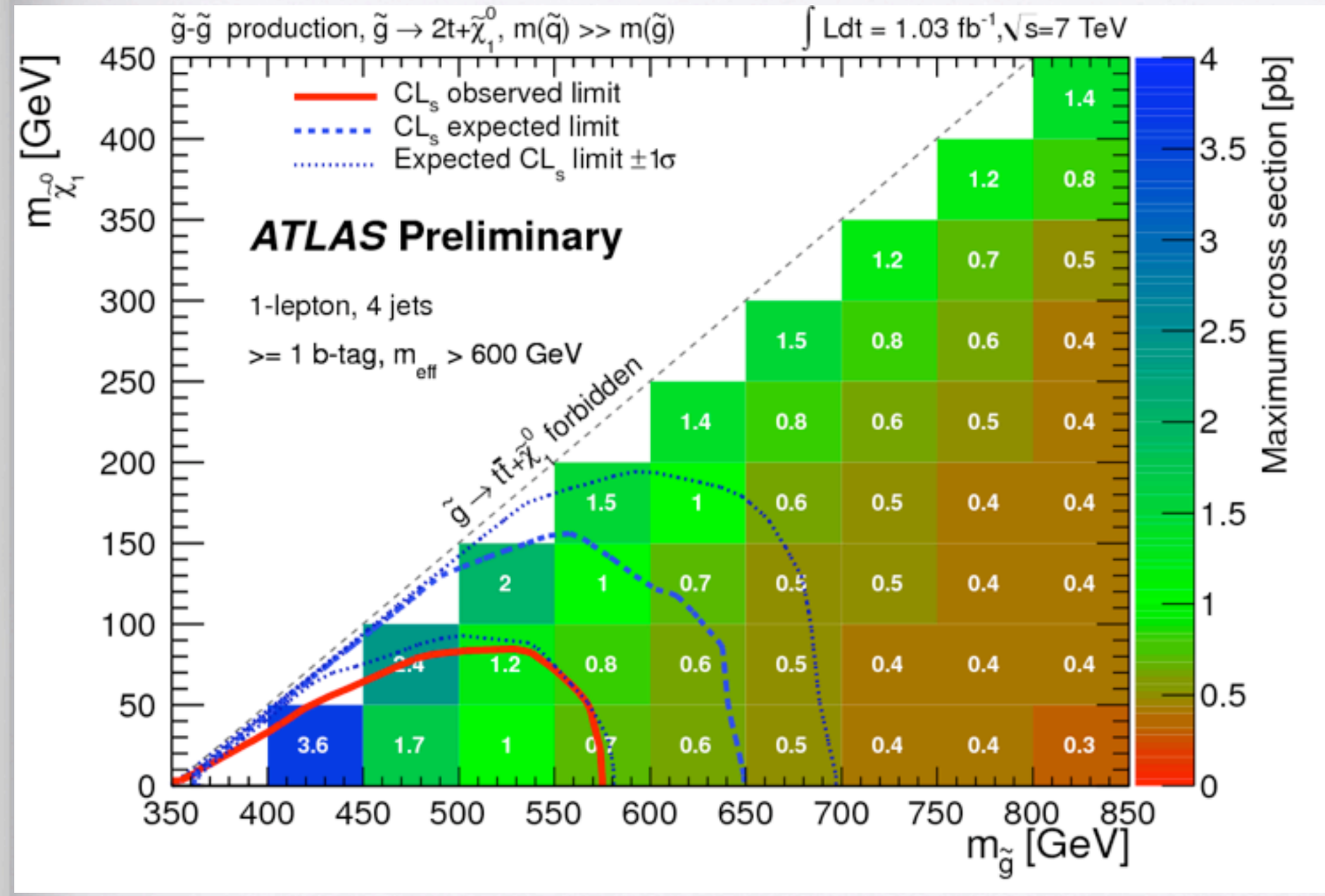
Most Degenerate

m_{LSP}=0.7 msq



Example of model independent searches

ATLAS LP



But more than 350GeV mass differences for this case

See studies by Alwall, Wacker....

MUED and LHC

- A Model that all SM particle lives in 5th dimention, Z_2 compactification for KK parity

- small mass splitting as in KKLT model. particles in the same KK levels are degenerate.

$$m^2_{X^{(n)}} = \frac{n^2}{R^2} + m^2_{X^{(0)}} + \delta m^2_{X^{(n)}} \quad \text{(Boson)},$$
$$m_{X^{(n)}} = \frac{n}{R} + m_{X^{(0)}} + \delta m_{X^{(n)}} \quad \text{(Fermion)},$$

- Dark matter is lightest KK odd particle~ U(1) gauge boson KK mode

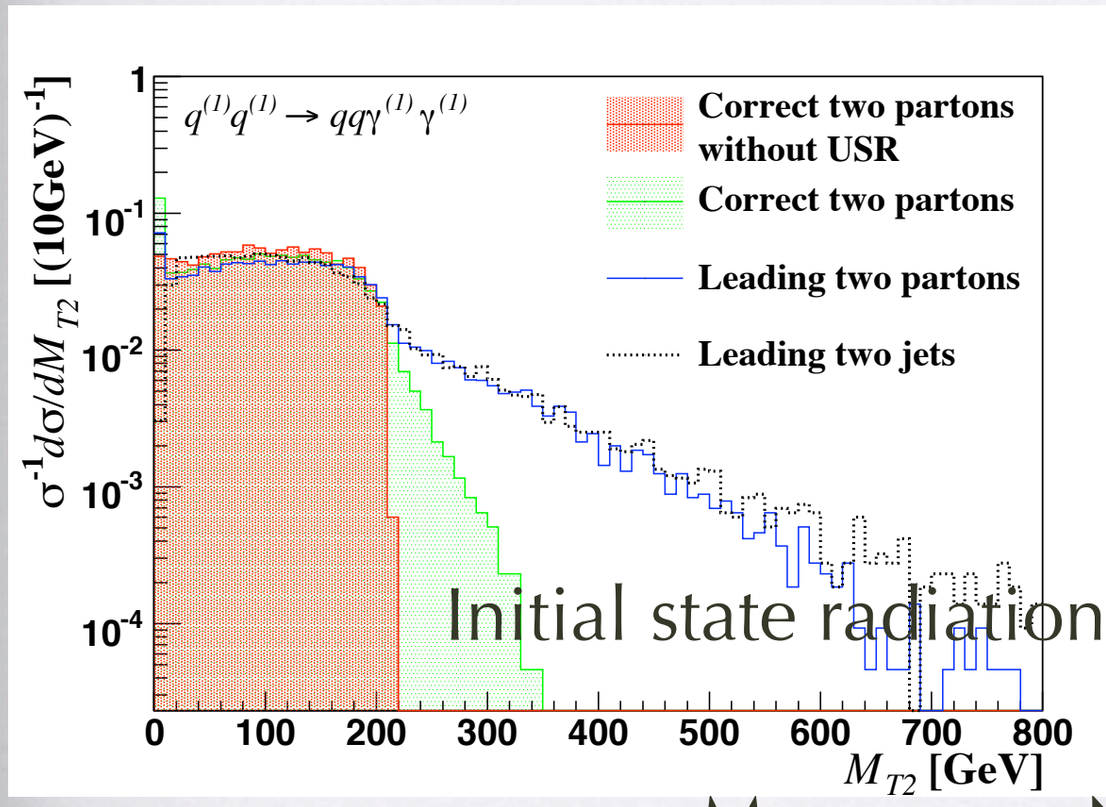
- mass splitting within 20%, but easier than SUSY, large cross section and lepton branching ratio

$m_{\gamma^{(1)}}$	$m_{W^{(1)}}$	$m_{Z^{(1)}}$	$m_{e^{(1)}}$	$m_{L^{(1)}}$	$m_{d^{(1)}}$	$m_{u^{(1)}}$	$m_{Q^{(1)}}$	$m_{g^{(1)}}$	
800.1	847.3	847.4	808.2	822.3	909.8	912.5	929.3	986.4	GeV

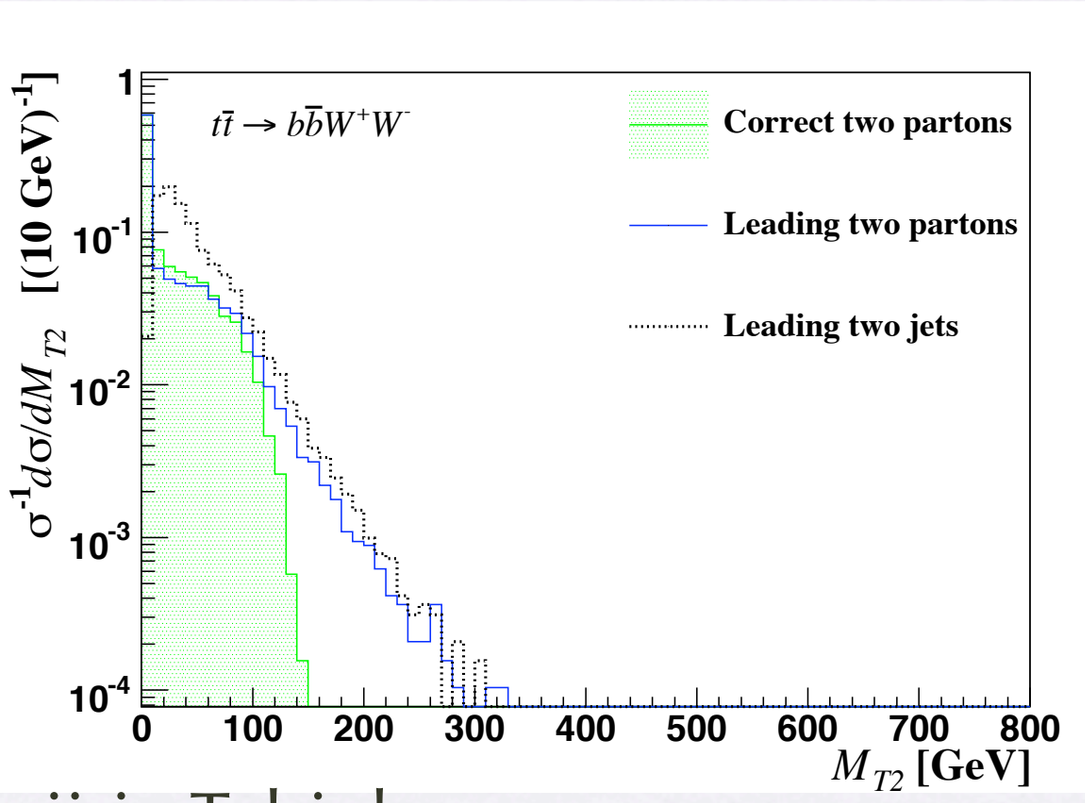
Table 1: Mass spectrum of first KK level for a benchmark point $(1/R, \Lambda R) = (800, 20)$

M_{T2} for background reduction MUED case

- calculate M_{T2} for leading two jets and m_{test}=0.
- tt distribution: leading jets tend to be b-jets, and input test mass is correct. They cannot extend too much beyond m_t.
- signal distribution: Not much high pT jets from MUED particle decay. The leading jet is initial state radiation.



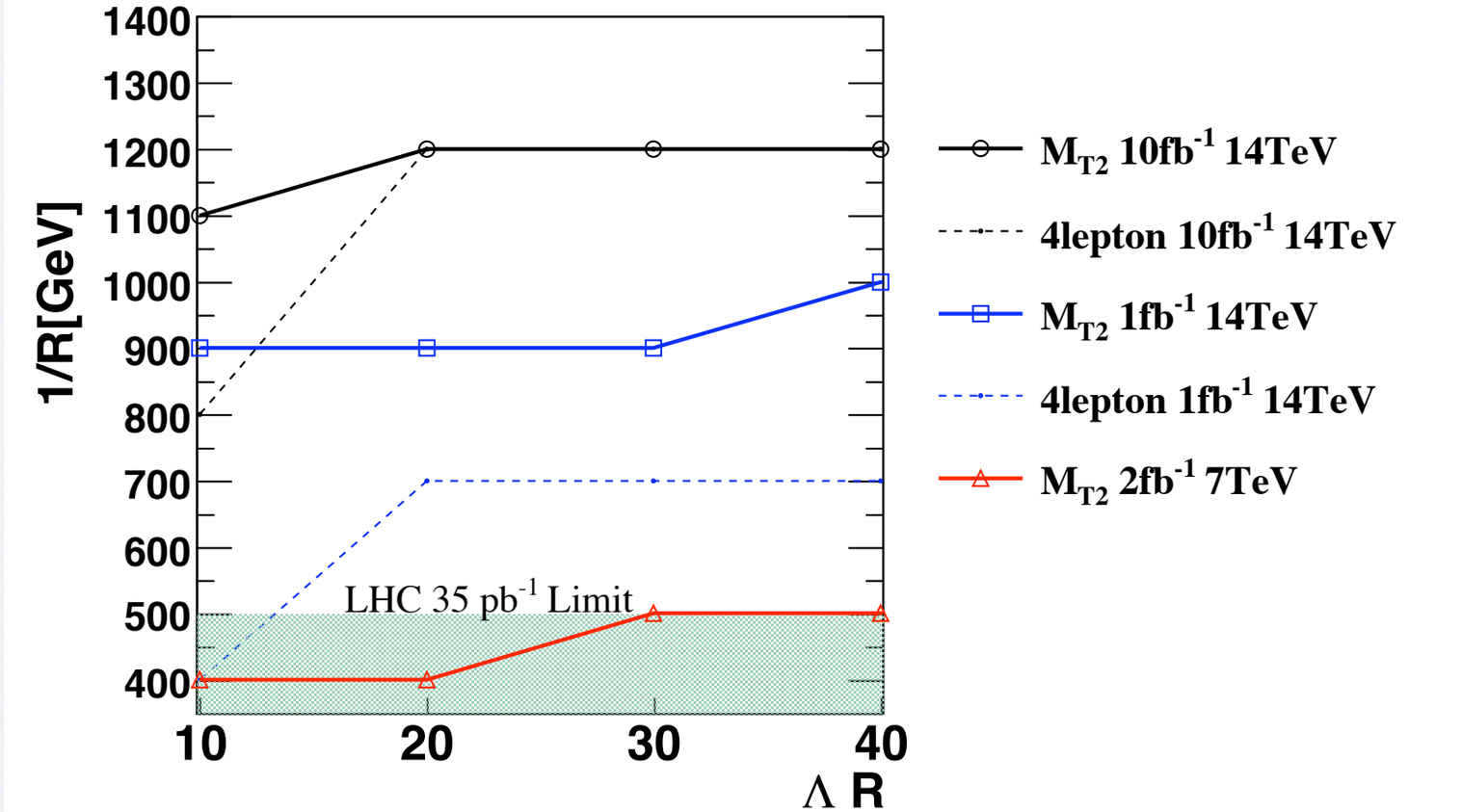
Initial state radiation



Murayama, Nojiri , Tobioka

Discovery in jets + lepton mode (theorist calculation)

- up to 1.2TeV for 10fb-1 at14TeV
- No b veto assumed. matrix element corrections for the SM background, and not for MUED signal (conservative)



- Dark matter favored region MUED at 1/R~1.5 TeV.
- Need Something similar for SUSY.

Any Question?